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Reduction of CO_2 emission by INCAM model in Malaysia biomass power plants during the year 2016

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ABSTRACT

As the world's second largest palm oil producer and exporter, Malaysia could capitalize on its oil palm biomass waste for power generation. The emission factors from this renewable energy source are far lower than that of fossil fuels. This study applies an integrated carbon accounting and mitigation (INCAM) model to calculate the amount of CO_2 emissions from two biomass thermal power plants. The CO_2 emissions released from biomass plants utilizing empty fruit bunch (EFB) and palm oil mill effluent (POME), as alternative fuels for powering steam and gas turbines, were determined using the INCAM model. Each section emitting CO_2 in the power plant, known as the carbon accounting center (CAC), was measured for its carbon profile (CP) and carbon index (CI). The carbon performance indicator (CPI) included electricity, fuel and water consumption, solid waste and waste-water generation. The carbon emission index (CEI) and carbon emission profile (CEP), based on the total monthly carbon production, were determined across the CPI. Various innovative strategies resulted in a 20%–90% reduction of CO_2 emissions. The implementation of reduction strategies significantly reduced the CO_2 emission levels. Based on the model, utilization of EFB and POME in the facilities could significantly reduce the CO_2 emissions and increase the potential for waste to energy initiatives.

1. Introduction

The rise in energy demand and the corresponding rise in greenhouse gas (GHG) emissions are causing climate change (Kerdsuwan and Laohalidanond, 2011). Fig. 1 illustrates CO_2 emissions by region from 1990 to 2030. CO_2 emission levels are estimated to increase drastically for some regions of the world within 40 years. One key approach to addressing climate change is to replace fossil fuels with renewable energy for electricity production. Thus, reliance on fossil fuels without any conservation effort or increase in renewable energies to fulfill our energy demand will eventually lead to catastrophic global impacts.

The development of non-fossil fuel energy sources is essential for reducing GHG, avoiding fossil fuel resource depletion and coping with fluctuating fossil fuel prices (Talebian-Kiakalaieh et al., 2013; Maceiras et al., 2011; Santori et al., 2012). CO_2 emissions can be substantially reduced if biomass replaces fossil fuels for power generation. Indeed, unlike fossil fuels, burning renewable biomass is considered neutral in GHG emissions (Ibrahim, 2016). Trees take in carbon dioxide from the atmosphere and convert it into biomass; whether trees are burned or decompose naturally, they release the same amount of carbon dioxide (Cho, 2011). Also, the carbon that is released when biomass is burned is re-absorbed by other plants in their growth cycle. However, when fossil fuels are burned, they release CO_2 that has been trapped for centuries, adding carbon to the atmosphere (Biomass Power Association, 2011). Fig. 2 illustrates that renewable energies generate significantly lower GHG emissions compared with fossil fuels including natural gas, oil and coal.

Given Malaysia's tropical biodiversity, conversion of waste (biomass) to energy is a promising approach to establishing sustainable energy production. Waste management was originally adopted for the purposes of waste volume reduction and maintaining high levels of public hygiene. However, over the years, waste management concept has evolved to include the concepts of waste prevention, waste recycling and waste to energy (Hadidi and Omer, 2017; Chen, 2016; Schwarzbock et al., 2016). Malaysia is ranked as the world's second largest palm oil producer, next to Indonesia. In fact, Malaysia's palm oil production exceeded 21.25 MMT in 2014, and has been increasing annually since 2009. Malaysia's palm plantation area and amount of crude palm oil production

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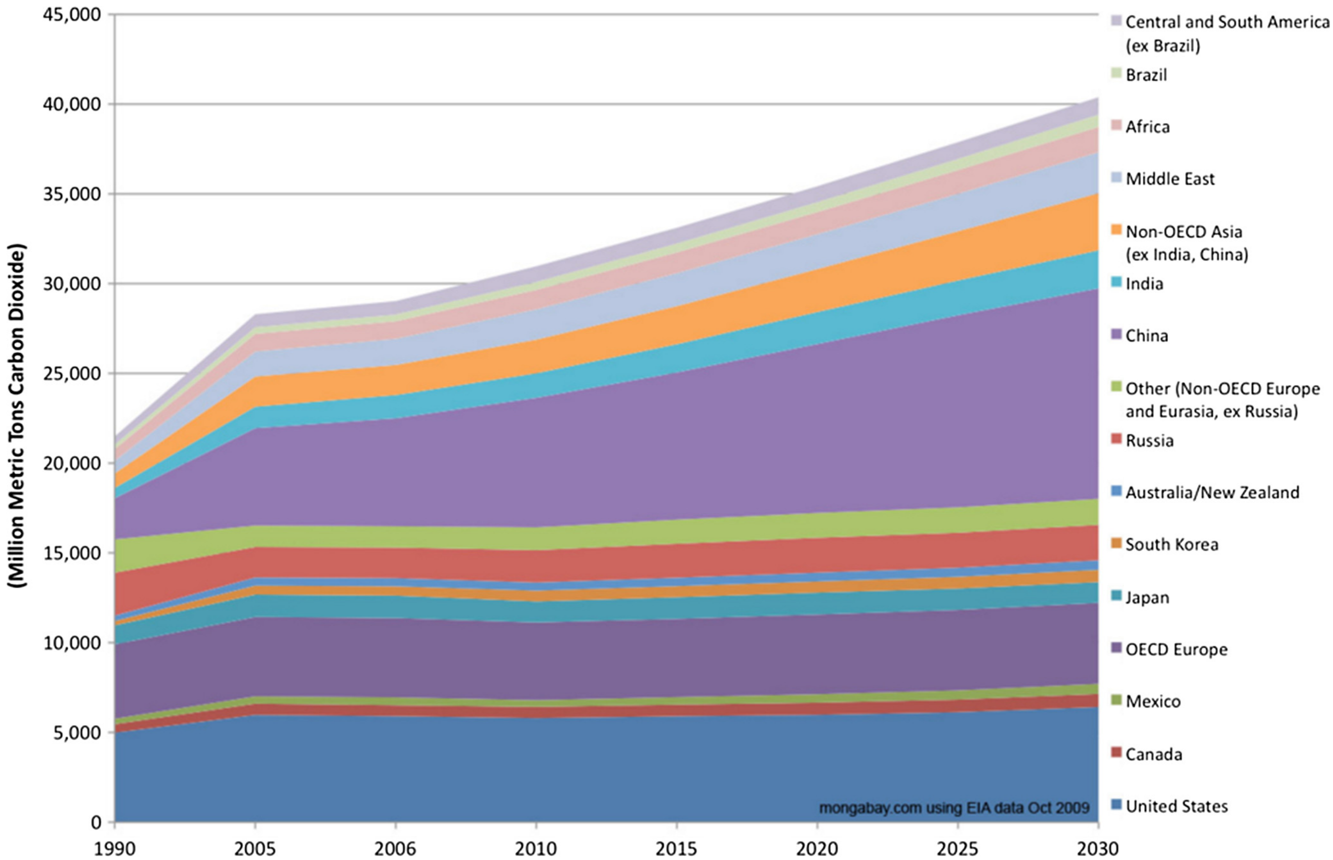

Fig. 1. World CO_2 emission levels by region between 1990 and 2030.

significantly increased from 4.7 to 5.4 million hectares and 17.6 to 19.8 million tonnes, respectively, between 2009 and 2014 (Aditiya et al., 2016).

The oil palm industry yields a tremendous amount of biomass waste such as frond, trunk, mesocarp fibres, palm kernel shell, empty fruit bunches (EFB), and palm oil mill effluent (POME). These wastes are a potential source for energy generation. However, only a small portion of this waste is currently utilized for steam and electricity generation (Mahlia et al., 2003; de Souza et al., 2010). A large fraction is simply burned or used as landfill (Lahijani and Zainal, 2011). Thus, the government and industry alike are seeking ways to utilize this massive oil palm industry wastes. For instance, heat from EFB combustion can be captured in a boiler to produce steam. POME, the voluminous liquid waste from the oil palm industry, is retained in ponds to reduce its toxicity and releases methane gas. If harvested properly the valuable methane fuel can be used for electricity, steam or heat generation.

In accordance with global efforts to produce renewable energy and reduce CO_2 emissions, Malaysia has developed strategic plans for increasing its share of renewable energy sources. Iskandar Malaysia, an innovative economic development zone in Johor has developed a Low Carbon Society Blueprint, called IM 2025, with a target to reduce carbon intensity by 58% by 2025 from 2005 carbon level. The Malaysian government designed a roadmap to make this economic development zone a ‘‘strong sustainable metropolis of international standing" by 2025, producing only 18.9 $MtCO_2qe$ GHG emissions, 40% lower than the projected amount (Low Carbon Society Blueprint for Iskandar Malaysia 2025, 2014).

Life cycle assessment (LCA) is a common tool used to study environmental impacts associated with all stages of a manufactured product's life cycle, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. For example, the environmental impacts in the different parts of the palm oil supply chain have been identified using LCA in nurseries (Halimah et al., 2010), fresh fruit bunches (Zulkifli et al., 2010), crude palm oil (Vijaya et al., 2010a), and bio-char from empty fruit bunches (Harsono et al., 2013). LCA is also used for palm kernel oil (Vijaya et al., 2010b), refined palm oil (Tan et al., 2010), bio-hydrogenated diesel from palm oil (Boonrod et al., 2017), GHG emission of palm biodiesel (Abdul-Manan, 2017), and impact of palm oil feedstock on products (Martinez et al., 2017). Alternatively, a simpler integrated carbon accounting model (INCAM) considers direct and indirect carbon emissions (Hashim et al., 2015).

The main objective of this paper is to apply the INCAM model to determine the amount of CO_2 emissions from two biomass thermal power plants that use oil palm waste to produce energy. In this paper, two case studies are analyzed. The first case study investigates the CO_2 emission from Bio-Xcell company, a central utility facility situated in Iskandar Malaysia which uses EFB to produce steam. The other company, Kulim Group Oil Palm Mill use POME as an alternative fuel for firing gas turbines to produce electricity. From the model, various innovative strategies are proposed to reduce CO_2 emissions. The findings from our study provide basic, useful data for developing renewable energy policies to lower CO_2 emissions from the industrial sectors in Iskandar Malaysia region.

2. Methods

The steps to determine the reduction in CO_2 emissions levels with the INCAM model are illustrated in Fig. 3. Initially, each process is divided into smaller scoping units known as carbon

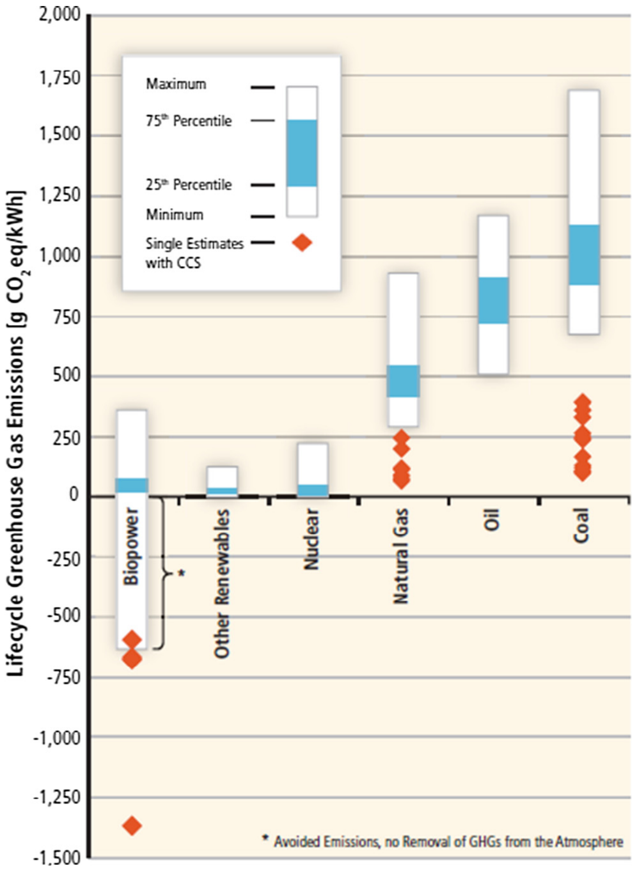

Fig. 2. Lifecycle GHG emissions of renewable energy, nuclear energy, and various fossil fuels.

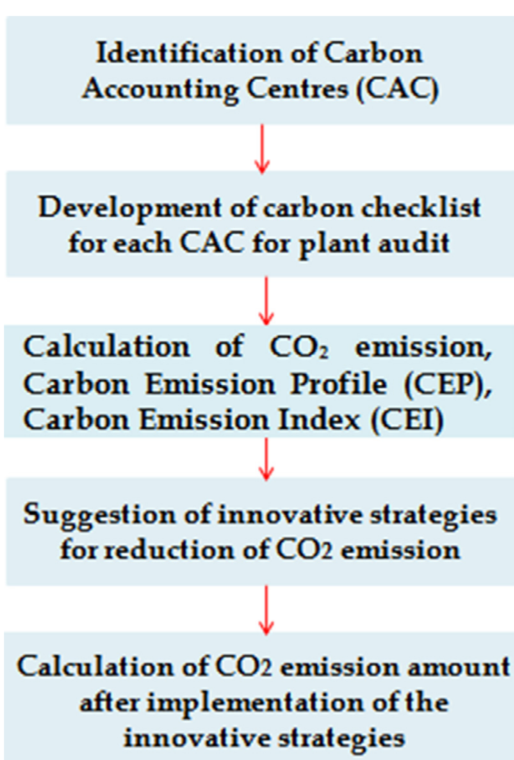

Fig. 3. Integrated carbon accounting and mitigation (INCAM) framework steps.

accounting centers (CACs) for easy monitoring of the CO_2 emission levels. Next, a carbon checklist is developed to identify the carbon emission source for each division, and a plant audit is performed. Most importantly, the average amount of CO_2 emission throughout the year 2016 is reported in this study. In fact, there is a small difference in CO_2 emission levels in different seasons, thus application of average amount was selected as the most logic choice. Five main emission contributors-fuel, water, and electricity consumption, waste water and solid-waste generation are identified as Carbon Performance Indicators (CPI). The Carbon Emission Index (CEI) for each CPI is based on CO_2 emission factors (Hashim et al., 2015; The Climate Registry, 2014). The CPI with the highest emissions is identified as the hotspot based on the Carbon Emission Profile (CEP). After the hotspot is identified, innovative strategies are suggested to reduce carbon emissions. The carbon emissions are again calculated after the implementation of innovative strategies to reduce carbon emissions. Finally, the carbon emission reduction in each plant is measured and then compared to identify the plant with the highest reduction.

3. Case studies

The effectiveness of the INCAM methodology is evaluated for the two companies, namely Bio-Xcell and Kulim Group Oil Palm Mill. Bio-Xcell, located in Nusajaya, Iskandar Malaysia uses EFB as fuel for steam production. The steam is supplied to other nearby power plants for generating heat and electricity. The Bio-Xcell plant has three divisions: steam generation, waste water treatment and chiller plants. At 500 °C temperature and 42 bar pressure, 7135 tonnes/month output rate steam was produced. The Kulim Group Oil Palm Mill is situated in Kulai, Johor. In this facility, POME retained in ponds releases methane gas and electricity is generated from combusting methane in a gas engine. Biogas or methane from the POME pond is trapped, conditioned and scrubbed before combustion. The production output for this company is 160,000 m^3/month (67,680 tone/month) of methane gas. The data for both case studies are based on monthly average in 2016.

3.1. Process description for Bio-Xcell

Fig. 4a depicts the process flow of the Bio-Xcell facility. The main divisions are the steam generation plant (boilers, biomass storage, and LPG farm), water pre-treatment plant and chiller plant. Two bi-water tube boilers are fueled by biomass and a fire tube boiler uses LPG. Raw water is pre-treated in the water pre-treatment plant to insure high-quality steam. In the LPG farm, the liquefied petroleum gas is treated and vaporized before entering the boiler. The biomass is stored in a storehouse and carried on a conveyer belt into the boiler. Three types of fuel consumption data were collected—diesel (on-site transportation), LPG (fire-tube boiler) and EFB (water-tube boiler). The electricity generation data for each section was not available, but the general electricity consumption data for the entire plant is assumed to be from the chiller plant. The feedstock supplied to Bio-Xcell is wet EFB with about 5–7% moisture (Abdullah and Sulaiman, 2013). Based on calculations, an estimated 5% of water and solid fuel consumption were wastewater and solid waste. As per observations and discussions with the plant engineers, a 5% solid waste generation was assumed since EFB could combust well and a relatively small amount of ash and coke remained at the end of each process.

3.2. Process description for Kulim Group

The process flowchart of the Kulim Group plant is described in Fig. 4b. The main two sections considered in this study are the

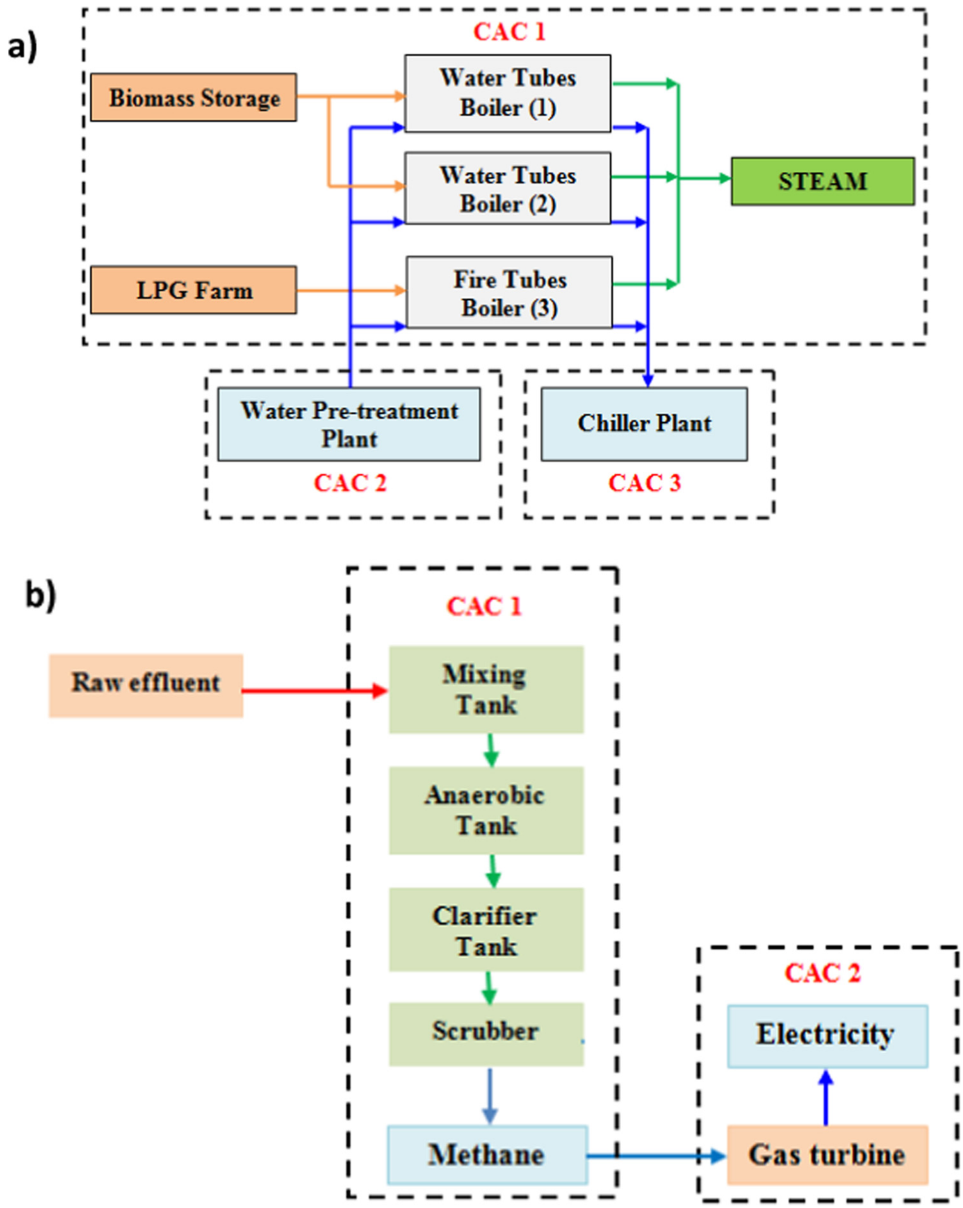

Fig. 4. The process flow diagram of (a) Bio-Xcell and (b) Kulim plants.

methane gas production (CAC 1) and electricity production (CAC 2). In details, the raw effluent is fed to the mixing tank for pre-treatment and then sent to the anaerobic tank for microbiological process which includes:

1. Hydrolysis (complex molecules are broken down into simple molecules).
2. Acidogenesis (production of various types of acids, and ammonia (NH_3), CO_2, H_2S, and H_2).
3. Acetogenesis (production of acetic acid (CH_3CO_2H), CO_2, and H_2).
4. Methanogenesis (the last stage for methane (CH_4) gas production).

3.3. Assessment of carbon in each unit

The steps to identify the carbon accounting centers, determine the total monthly carbon emissions, calculate the CEIs and reduce CO_2 emissions are described here. Several strategies are considered to reduce the carbon emissions across the CPIs.

3.3.1. Step 1: Identification of CAC

3.3.1.1. Bio-Xcell central facility. Three CAC breakdowns are used in this study; CAC1 represents the steam-generation process, which includes three sub-CACs of biomass storage, along with the LPG farm and boilers. CAC2 and CAC3 represent the water pretreatment and chiller plants.

3.3.1.2. Kulim Group bio-gas facility. For this case study, two CAC breakdowns were performed. CAC1 represents the methane production process and CAC2 for electricity generation process.

3.3.2. STEP 2: Carbon checklist development and plant audit

The carbon emission sources in each CAC are identified in this step. Table 1 lists the various carbon emission sources for each CAC. The audit process involved a site visit and data collection of the companies' utility bills, procurement reports and domestic waste reports. The audit process provided significant information about the monthly consumption and generation of five carbon per-

formance indicators (CPI) fuel, water, electricity consumption, wastewater, and solid waste generation. The values, listed in Table 2, are subsequently used for carbon emission analysis in the next step.

3.3.3. STEP 3: Establish carbon emission profile (CEP) and carbon emission index (CEI)

Table 3 summarizes the carbon profile (CP) and carbon index (CI) of each CAC subsection. The highest total monthly CO_2 emission is released by the boilers and POME consumption in the EFB and POME utilization processes, respectively. Thus, the steam generation in the boilers and methane gas generation process are identified as the hotspots in these case studies. The first and most important information needed was the amount of CO_2 emissions for each CPI. The emission factors related to each CPI were collected from the literature (Hashim et al., 2015; The Climate Registry, 2014). Meanwhile, the monthly carbon emission equivalent (MCEE) was calculated by multiplying the CO_2 emissions and monthly amount of each CPI's consumption or generation (Eq. (1)). The carbon profile (CP), and carbon index (CI) for each CAC are determined by Eqs. (2) and (3). The CEP and CEI for each CPI are calculated by Eqs. (4) and (5).

Table 1
Carbon checklist for Bio-Xcell and Kulim plants.

Carbon Performance Indicators (CPI)		BIO-XCELL			KULIM	
		CAC1 Steam Generation	CAC2 Water Pre-treatment plant	CAC3 Chiller plant	CAC1 Methane Production	CAC2 Electricity Generation
Fuel	POME	–	–	–	√	–
	EFB	√	–	–	–	–
	Diesel	√	–	–	–	–
	LPG	√	–	–	–	–
	Methane	–	–	–	–	√
Water		√	√	√	√	–
Electricity		–	–	√	√	–
Waste Water		–	√	√	√	–
Solid Waste		√	–	–	√	–

Table 2
Monthly consumption and generation in each Carbon Accounting Center (CAC).

Carbon Performance Indicators (CPI)		Emission Factor (kg·CO_2e/unit)	Monthly consumption or generation				
			BIO-XCELL			KULIM	
			CAC1 Steam Generation	CAC2 Water Pre-treatment plant	CAC3 Chiller plant	CAC1 Methane Production	CAC2 Electricity Generation
Fuel	POME (m^3)	292	–	–	–	2.4×10^5	–
	EFB (Tone)	1100	2.25×10^3	–	–	–	–
	Diesel (Liter)	2.7	9.73×10^2	–	–	–	–
	LPG (kg)	1.53	1.82×10^6	–	–	–	–
	Methane (m^3)	2	–	–	–	–	1.6×10^5
Water (m^3)		300	7.27×10^3	5.98×10^3	5×10^3	1.35×10^4	–
Electricity (kWh)		0.727	–	–	2.06×10^6	1.2×10^5	–
Waste Water (m^3)		1670	–	3×10^2	2.5×10^2	9×10^3	–
Solid Waste (kg)		997.9	1.12×10^2	–	–	6×10^3	–

Table 3
Carbon profile (CP) and carbon index (CI) for each Carbon Accounting Center (CAC).

Carbon Performance Indicators (CPI)		Monthly carbon emission equivalent (MCEE) (t CO_2e)						
		BIO-XCELL				KULIM		
		CAC1 Steam Generation	CAC2 Water Pre-treatment plant	CAC3 Chiller plant	Total	CAC1 Methane Production	CAC2 Electricity Generation	Total
Fuel	POME (m^3)	–	–	–	–	7×10^7	–	7×10^7
	EFB (Tone)	2.5×10^6	–	–	2.8×10^6	–	–	
	Diesel (Liter)	2.6×10^3	–	–		–	–	
	LPG (kg)	2.8×10^5	–	–		–	–	
	Methane (m^3)	–	–	–	–	–	3.2×10^5	3.2×10^5
Water (m^3)		2.2×10^6	1.8×10^6	1.5×10^6	5.5×10^6	4.1×10^6	–	4.1×10^6
Electricity (kWh)		–	–	1.5×10^6	1.5×10^6	8.7×10^4	–	8.7×10^4
Waste Water (m^3)		–	5×10^5	4.2×10^5	9.2×10^5	15×10^6	–	15×10^6
Solid Waste (kg)		1.1×10^5	–	–	1.1×10^5	6×10^6	–	6×10^6
Total monthly CO_2e (tCO_2e)		5.1×10^6	2.3×10^6	3.4×10^6	10.8×10^6	9.5×10^7	3.2×10^5	9.532×10^7
% Carbon Profile, CP		47.1	21.3	31.6	100	99.7	0.3	100
Carbon Index (tCO_2e), CI		714.8	322.4	479.3	1516.5	1406.6	4.7	1411.3

$$\text{Monthly carbon emission equivalent (MCEE)} = \text{Monthly consumption orgeneration} \times \text{Emission factor} \tag{1}$$

$$\text{CAC carbon profile (CP)} = \frac{\text{Total monthly } CO_2 \text{ of each CAC}}{\text{Total monthly } CO_2 \text{ equivalent } (tCO_2e)} \times 100 \tag{2}$$

$$\text{CAC carbon index (CI)} = \frac{\text{Total monthly } CO_2 \text{ of each CAC}}{\text{Total monthly of production (tone) in a month}} \tag{3}$$

$$\text{Carbon emission profile (CEP)} = \frac{\text{Total monthly } CO_2 \text{ of each CPI}}{\text{Total monthly } CO_2 \text{ equivalent } (tCO_2e)} \times 100 \tag{4}$$

$$\text{Carbon emission index (CEI)} = \frac{\text{Total monthly } CO_2 \text{ of each CPI}}{\text{Total amount of production (tone) in a month}} \tag{5}$$

3.3.4. STEP 4: Recommended strategies for carbon emission reduction

Table 4 summarizes the recommended strategies for reducing CO_2 emissions in two cases. At Bio-Xcell, we recommended decreasing fresh water intake to reduce CO_2 emissions. Recycled water could be utilized in boilers, water treatment, and chiller plants in CAC1, CAC2, and CAC3, respectively. Next, we preferred using natural gas instead of diesel fuel in the biomass storage section (CAC1) to significantly reduce the CO_2 emissions.

We also recommended using higher-efficiency cooling tools to reduce electricity consumption (Hashim et al., 2015). Utilization of briquette EFB as a solid fuel instead of shredded and pellet EFB could increase the energy content of EFB by increasing the fuel calorific value (C_V) (Yuhazri et al., 2012). Also, the furnace design and the draft calibrations were improved to help ensure complete combustion of the biomass (Olisa and Kotingo, 2014). The difference between monthly carbon emissions of each CPI before and after implementation of reduction strategies is reported in Table 4 as "CPI reduction (%)". In fact, about 18.2–25% of emission reductions across the CPIs were achieved due to the implementation of the recommended strategies.

In the Kulim plant, the target was to use as much POME as possible to generate a steady supply of methane. Thus, the amount of POME consumption should not be decreased when implementing the CPI reduction strategy. However, application of a highly efficient anaerobic reactor could increase methane production. In addition, the other main factor that significantly effect on the amount of electricity production is the gas-turbine efficiency for combusting methane gas. Thus, the first strategy to reduce current CO_2 emission was to decrease fresh and wastewater consumption by utilizing recycled water (Hashim et al., 2015). Next, application of cooling tools, which require less energy was suggested to reduce the electricity consumption significantly. The Kulim plant produced sludge as solid waste. Since about 98% of the sludge is water, water recycling could have an impact in reducing the amount of solid waste. Table 4 shows the difference between monthly carbon

Table 4
Carbon emission reduction strategies and Carbon Performance Indicator (CPI) reduction percentage.

Carbon Performance Indicators (CPI)		BIO-EXCELL			KULIM		
		CAC	Strategy	CPI reduction (%)	CAC	Strategy	CPI reduction (%)
Fuel	POME + Methane	–	–	–	1, 2	–	–
	EFB + Diesel + LPG	1	Natural gas utilization instead of diesel	1	–	–	–
Water consumption		1, 2, 3	Recycle water utilization in all the process	25.0	1	Recycle water utilization in all the process	25.0
Electricity consumption		3	High efficiency equipment	20.0	1	High efficiency equipment	20.0
Waste water generation		2 & 3	Recycle and pre-treatment	18.5	1	Recycle and pre-treatment	50.0
Solid waste generation		1	Application of briquette EFB instead of shredded and pellet EFB	18.2	1	Separation and recycling of sludge water and re-use in the process	90

Table 5
Carbon Index (CI) for each Carbon Accounting Center (CAC) after reduction strategy implementation.

Carbon Performance Indicators (CPI)		Emission Factor (kg·CO_2e/unit)	Monthly carbon emission equivalent (MCEE) (t CO_2e)								
			BIO-EXCELL					KULIM			
			TC or TG[a]	CAC 1 Steam Generation	CAC 2 Pre-treatment plant	CAC 3 Chiller plant	Total	TC or TG[a]	CAC1 Methane Production	CAC 2 Electricity Generation	Total
Fuel	POME (m^3)	292	–	–	–	–	–	2.4×10^5	7×10^7	–	7×10^7
	EFB (Ton)	1100	2.25×10^3	2.5×10^6	–	–	2.78×10^6	–	–	–	–
	Natural Gas (Liter)	0.002	9.74×10^2	2	–	–		–	–	–	–
	LPG (kg)	1.53	1.81×10^6	2.8×10^5	–	–		–	–	–	–
	Methane(m^3)	2	–	–	–	–	–	1.6×10^5	–	3.2×10^5	3.2×10^5
Water (m^3)		300	1.37×10^4	1.64×10^6	1.35×10^6	1.13×10^6	4.12×10^6	1×10^4	3×10^6	–	3×10^6
Electricity (kWh)		0.727	1.65×10^5	–	–	1.2×10^6	1.2×10^6	9.6×10^4	7×10^4	–	7×10^4
Waste water (m^3)		1670	4.49×10^2	–	4.1×10^5	3.41×10^5	7.51×10^5	4.5×10^3	7.5×10^6	–	7.5×10^6
Solid Waste (kg)		997.9	92	9.2×10^4	–	–	9.2×10^4	600	6×10^5	–	6×10^5
Total Monthly CO_2e (tCO_2e)				4.51×10^6	1.76×10^6	2.67×10^6	8.94×10^6	–	8.1×10^7	3.2×10^5	8.132×10^7
Carbon Profile (%)				50.47	19.7	29.86	100	–	99.61	0.39	100
Carbon Index (tCO_2e)				632.58	246.7	374.21	1253.49	–	1196.8	4.73	1197.19

[a] Total consumption/generation of each fuel/material in a month.

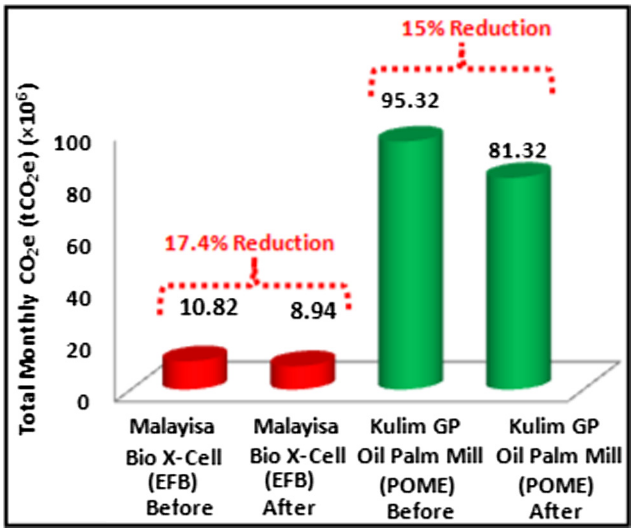

Fig. 5. Total monthly CO_2 emission before and after implementation of reduction strategies.

emissions of each CPI before and after implementation of reduction strategies as "CPI reduction (%)". In fact, about 20–90% reduction of various CPIs are attributed to the implementation of the recommended strategies.

Data for CI of each CAC following the reduction strategies are summarized in Table 5. Initially, the CO_2 emissions in the Bio-Xcell and Kulim plants were 10.82×10^6 and 9.552×10^7 tCO_2e, respectively; however, after emission reduction strategies were implemented, CO_2 emissions decreased to 8.94×10^6 and 8.15×10^7 tCO_2e, respectively. The total monthly CO_2 emissions related to the two case studies before and after reduction strategies were implemented appear in Fig. 5, with 17.4% and 15% reduction for Bio-Xcell and Kulim, respectively.

The bar charts in Fig. 6 compare the CEIs of the two plants before and after the implementation of reduction strategies. CEI is the main indicator of whether the strategies to reduce CO_2 emissions are successful. In general, all the CEIs across the CPI for the two companies decreased. For example, in Bio-Xcell, the CEI for fuel and water significantly decreased after the reduction strategies were implemented.

Fig. 7 presents four pie charts of the CEP of the two cases before and after the reduction strategies. The hot spot in each case study is highlighted in the pie charts. Fuel and water consumption are the hot spots for the Bio-Xcell companies due to the largest CEP while POME consumption and waste water generation are the hot spots for Kulim. Nonetheless, the CEP for fuel consumption significantly increases from 47.7% to 80.7%. Notably, the solid waste generation declines from 40.9% to 6.9% (90% reduction), which suggest that the reduction strategies are effective.

4. Comparison of CO_2 reduction: EFB and POME vs. coal and diesel

The CO_2 emissions from the different fuels are compared in this section. According to the EU Directive, CO_2 or GHG emissions reduction savings is calculated by Eq. (6) (Zutphen and Wijbrans, 2011):

$$\textit{Percentage of } CO_2 \textit{ reduction} = \frac{CO_2 \textit{ emission of fossil fuel consumption} - CO_2 \textit{ emission of POME consumption})}{CO_2 \textit{ emission of fossil fuel consumption}} \quad (6)$$

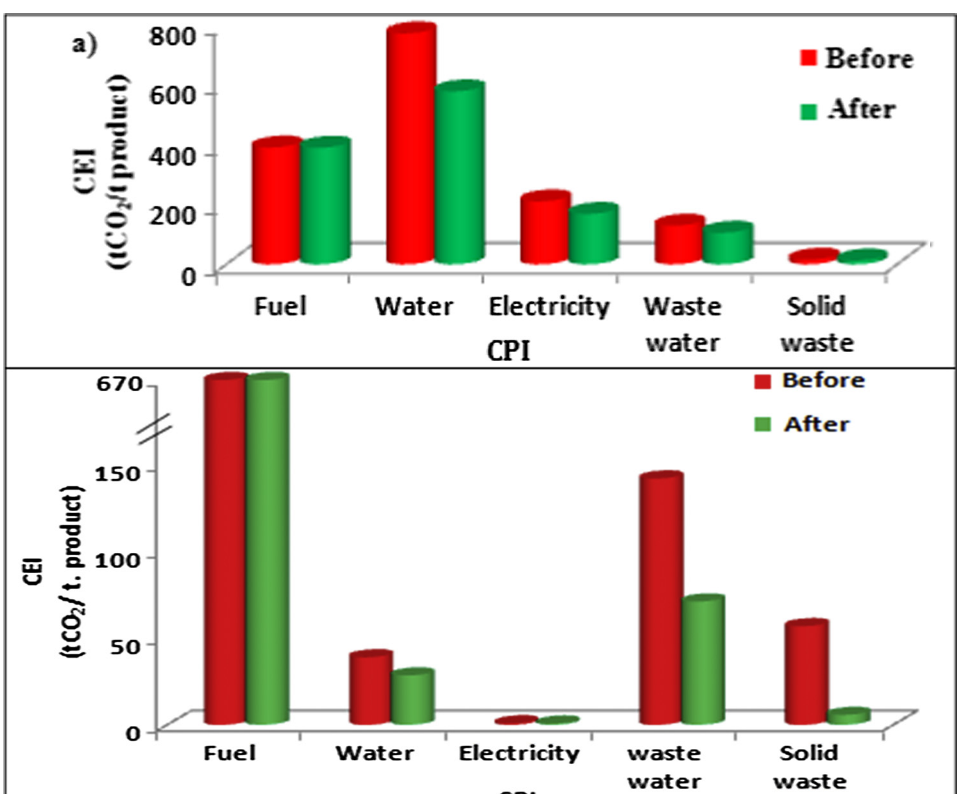

Fig. 6. Carbon Emission Index (CEI) of each Carbon Performance Indicator (CPI) before and after reduction strategy implementation; (a) Bio-Xcell and (b) Kulim plants.

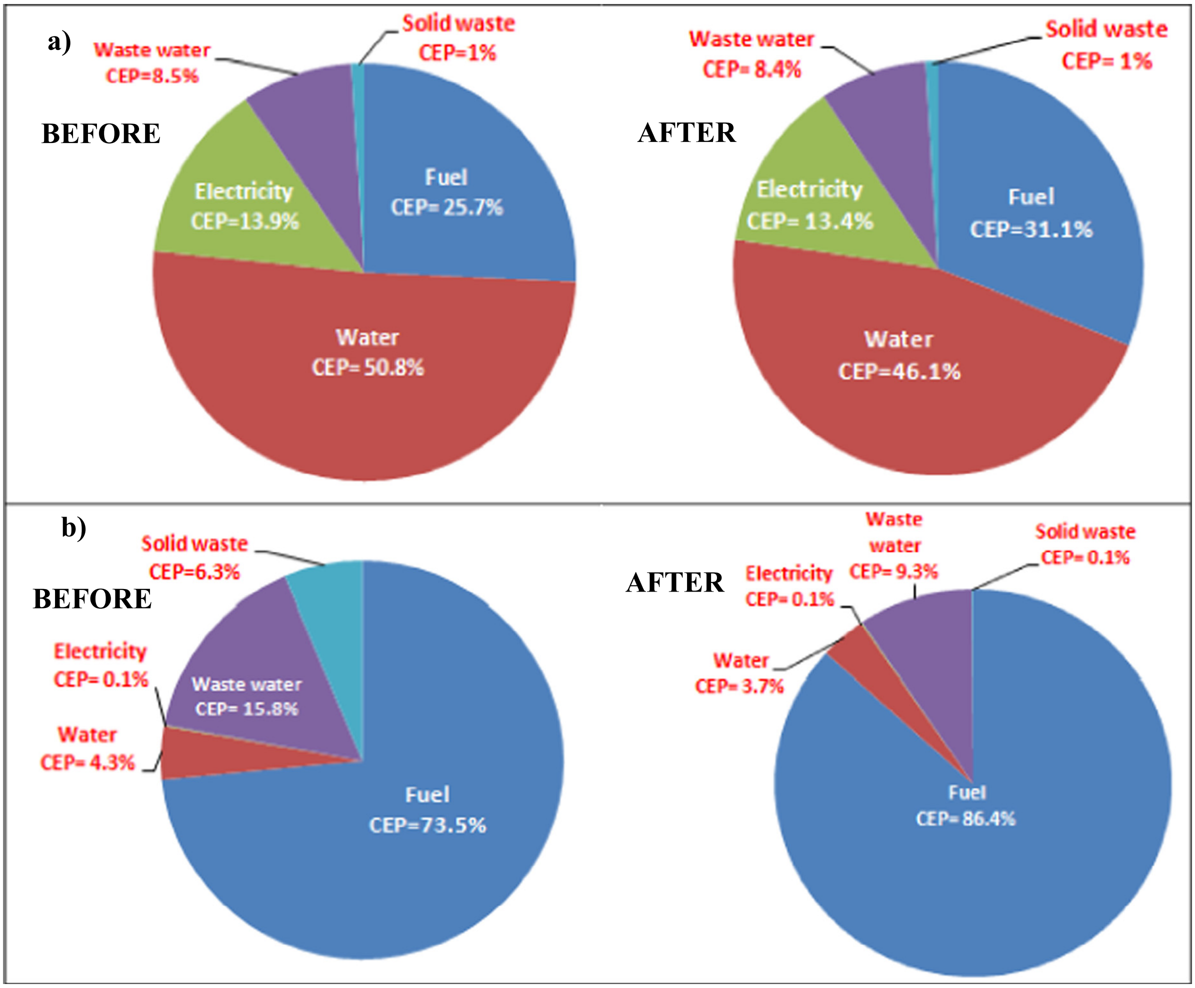

Fig. 7. Carbon Emission Profile (CEP) of each Carbon Performance Indicator (CPI) before and after reduction strategy implementation; (a) Bio-Xcell and (b) Kulim plants.

Table 6
Percentage of CO_2 reduction when fossil fuels are substituted with EFB and POME.

Fuel		EF (CO_2e/unit)	Consumption	Monthly carbon emission equivalent (t CO_2e)	CO_2 reduction by EFB or POME combustion (%)
Bio-Xcell	EFB	1100 kg/t	2250.3 tone	2.5×10^6	--
	Coal[a]	2566 kg/t	2250.3 tone	5.8×10^6	57.0
	Diesel[b]	2.7 kg/liter	2250.3 tone (2647.4×10^3 l)	7.15×10^6	65.0
Kulim	POME	292 kg/m^3	2.4×10^5 m^3	7×10^7	--
	Coal[a]	2566 kg/t	2.4×10^5 m^3 (1.92×10^5 tone)	4.93×10^8	85.8
	Diesel[b]	2.7 kg/liter	2.4×10^5 m^3 (2.4×10^8 l)	6.5×10^8	89.2

[a] Bituminous Coal ($C_{137}H_{97}O_9NS$), C = 89.06 wt%; O_2 = 6.72 wt%; S = 0.74 wt%.
[b] Diesel Fuel (C = 82.5% (ASTM D5291); H = 12.75% (ASTM D5291); S = 15 ppm (ASTM D240/516))".

CO_2 emissions from palm oil waste are lower compared to fossil fuels. Table 6 reveals that EFB and POME combustion could reduce CO_2 emissions by 57–65% and 85.8–89.2%, respectively, compared to coal and diesel. Olisa and Kotingo (2014) compared the utilization of EFB and natural gas in power generation and confirmed that EFB utilization was more economical and had significant advantages. Agricultural waste materials such as EFB or POME are abundantly available as renewable fuels for power generation. Utilization of these wastes translates into cheaper feedstock for power generation. Furthermore, significant reduction of capital costs, landfills, GHG emissions from EFB composting and POME ponds suggest that investment in renewable energy is economically viable (Aditiya et al., 2016; Sivasangar et al., 2015).

5. Effect of oil palm biomass power on Malaysia's economy

The amount of available oil palm biomass in Malaysia from the stated fresh fruit bunch (FFB) is reported in Table 7. The total production of oil palm biomass is about 114 Mt (Ng et al., 2012; Aditiya et al., 2016). Consequently, the potential energy that can be generated is equal to 48.2 Mt/y of oil equivalent based on the amount of available biomass. Although the value could provide sufficient electrical energy for Malaysia, huge amount of that is wasted due to the inefficient utilization of the available biomass.

Recently, the Malaysia's government has set a target to increase its biomass power capacity to 800 MW by 2020 and 500 MW is to be generated from oil palm biomass (KeTTHA, 2011; Ng et al.,

Table 7
The amount of available oil palm biomass in Malaysia.

Palm biomass	Quantity (Mt/y)[a]	Net calorific value (MJ/t)[b]	Potential energy (MTOE/y)[c]
EFB	22.1	18795	9.9
Mesocarpfibre	13.6	19055	6.2
Palm kernel shell	5.5	20093	2.6
POME	72.8	16992	29.5
Total	114		48.2

[a] Aditiya et al. (2016).
[b] Ng et al. (2012).
[c] 1 Mt of oil equivalent (MTOE) = 41868 MJ.

2012). Thus, production of 500 MW electricity from oil palm biomass will lead to huge financial saving as well as significant reduction of CO_2 emission level in Malaysia. In fact, Malaysia's electricity generation cost from fossil fuel in 2017 is equal to 15.2 RM per MW h (The Star Online, 2017). Therefore, based on the current rate 6.7×10^7 RM equivalent to 1.7×10^7 USD will be saved if oil palm biomass as a free feedstock is used instead of fossil fuel (coal or diesel).

6. Conclusions

The carbon accounting and mitigation method (INCAM) is utilized to assess ways to reduce CO_2 emissions from two Malaysian power plants. By utilizing EFB or POME in their power plants the two firms clearly lower their CO_2 emissions. The total monthly CO_2 emissions decrease by 17.4% and 15% for Bio-Xcell and Kulim, respectively. The power plants could decrease their fuel and water consumption expenses by replacing fossil fuels with oil palm waste namely EFB and POME biomass. The carbon emission indexes across the carbon performance indicators are substantially reduced by replacing fossil fuels with biomass fuels. The findings from this study could improve the regional position of Malaysia in the renewable energy technology market, considering that oil palms tree, the raw materials for EFB and POME, are abundant and a major agricultural crop in Malaysia. Investment and utilization of one of the most valuable local waste products in the energy generation process not only could eliminate various environmental concerns in Iskandar Malaysia, but also potential to improve the local economy.

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